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Short Communication

Connecting experts in the agricultural and meteorological sciences to advance knowledge of pest management in a changing climate

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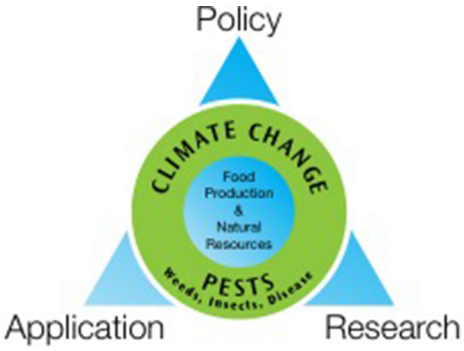
HIGHLIGHTS

- A low number of published papers focus on both pest biology and climate change.
- It is rare for individual authors to publish on both pest biology and climate change.
- Few collaborative relationships exist between pest biologists and climate scientists.
- The lack of collaboration is impacting our ability to solve societal problems associated with climate change and pests.

GRAPHICAL ABSTRACT



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ABSTRACT

There has been considerable progress in elucidating the physical aspects of climate change that directly impact food, feed, and fiber production. However, these impact assessments rarely account for climate induced changes associated with biological pests. The lack of collaboration between the pest management and climate science disciplines could be contributing to the problem. Therefore, we assessed research-based relationships, identifying possible barriers to and gaps in successful collaboration. We developed an algorithm capable of identifying author affiliation and associated disciplines. We found that pest management and climate scientists most often authored papers in their respective disciplines (>90%), but rarely in the opposing disciplines (<1%). Atopica, an international research group, is one of the few examples of how interdisciplinary collaborations have led to the co-production of knowledge to better understand and manage a pest responding to climate change. Researcher-to-researcher relationships, as demonstrated by Atopica, are an often overlooked area of science and key to solving major societal challenges.

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1. Introduction

In many places around the world, variation in the length and intensity of seasons is occurring more rapidly than the average, thus impacting organisms and their management in many agricultural and

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forestry systems. Mismatches in growth and development of species with their environment could have major implications not only for the species themselves but entire ecosystems. For example, dairy farmers across Norway now harvest grass for winter fodder earlier than they did 20 years ago (Mysterud et al., 2012); in southern Spain, fir trees are experiencing longer growing seasons, which could result in reduced fitness due to climate warming (Linares et al., 2012); and the full bloom date of apple and pear in South Africa has been earlier by 2 days/decade over the past 40 years (Grab and Craparo, 2011).

Unpredictability in weather patterns (e.g., early seasonal warmth, increased rainfall/drought) can also affect pest populations and their spatiotemporal movement in the environment, which in some years can add extra stress to crops and forests already under pressure from abnormal weather conditions. For example, in forests near the Kenai Peninsula, Alaska and Kluane National Park and Reserve, Yukon Territory, the frequency of outbreaks of spruce beetles have been correlated to warming temperatures, especially during the most recent period from 1971 to 1996 (Berg et al., 2006).

Weeds, insects, and diseases have always had an impact on agriculture and forestry ecosystems, but with recent changes in climate, these could become more significant (Rosenzweig et al., 2001). Many pests can proliferate under more stable conditions, and with constant variation in weather associated with climate change, they could adapt and become an even more difficult management and monitoring challenge. For example, Ziska (2001) has predicted that common cocklebur, a common weed in sorghum, will be more competitive with increasing CO_2. Climate change studies have also been conducted with insects and have primarily focused on changes in abundance and change in the distribution of species (Andrew et al., 2013). Bentz et al. (2010) created population models to suggest that movement of bark beetles of conifers in western North America would be to higher latitudes and elevations as a result of climate altered temperatures, thus increasing the potential for outbreaks and associated tree mortality in the coming century.

Despite how changing global climate is impacting the distribution, growth, and development of weeds, insects, and plant pathogens, climate scientists rarely work directly with pest management scientists in the various pest disciplines and vice versa. The needed expertise from the climate and pest management science fields is not always available at the same college or university, thus making cross-collaboration difficult and sometimes impossible. In other instances, time constraints or lack of resources prohibit the creation and sustaining of multi-disciplinary teams. These conditions can lead to relatively little knowledge exchange between climate scientists, who may focus on forests, agriculture, and urban ecosystems – primary locations for weeds, plant pathogens, and insects – and pest management scientists.

The USDA National Institute of Food and Agriculture's Climate Resilient Land Use for Agriculture and Forestry Program funds research to enable the nation's agriculture and forest lands to adapt to current and future climate conditions (including increased droughts and other extreme events), maintain or increase production, efficiently use soil and water resources, and improve soil, water and air conditions. In 2016, a group of pest management and climate scientists convened the National Forum on Climate and Pests (NFCP) through the USDA program with the objectives of (1) learning about critical research being conducted on the effects of climate on pests, microbes, and host-pest interactions; (2) understanding the strategic consequences of potential shifts in agriculture and forestry-related land use due to climate-related pest outbreaks or reductions; and (3) developing regional frameworks to support pest management decisions that will lead to more sustainable U.S. agriculture and forestry ecosystems in changing climates (Young, 2017). To date, little has emerged from the NFCP in strategizing how to develop resilient agricultural and forest ecosystems in the face of climate-induced changes in pest distribution and severity. Nevertheless, the NFCP may serve as a model for how pest management and climate scientists can generate usable information and build partnerships (Meadow et al., 2015).

What is increasingly being studied is the distribution of pests and changes in climate cycles in agricultural and forest ecosystems, and the resulting impacts on the environment, economies, and society and the need for better management and monitoring. Without coproduction of knowledge, which we describe based on the definition by Meadow et al. (2015), as the process of producing usable science through collaboration between scientists, slow progress will be made in improving understanding and generating the actionable science allowing for the creation of decision support tools for managers and effective policy for regulators.

Our objective was to determine the number of collaborative relationships between pest management and climate scientists using an algorithm capable of identifying author affiliation in published literature. We hypothesized that 1) the number of articles focused on either pests or climate change are higher than for the two disciplines combined and 2) individual authors publishing on both pests and climate change is uncommon. We describe the current state of collaboration and highlight an example of a success story from Europe, which we believe demonstrates the extent of the "silo effect" between two fields, and whether more extensive collaboration could help solve problems associated with climate change and pests.

2. Methods

A review was performed to quantify the collaborative relationships between researchers in the pest management and climate sciences. A

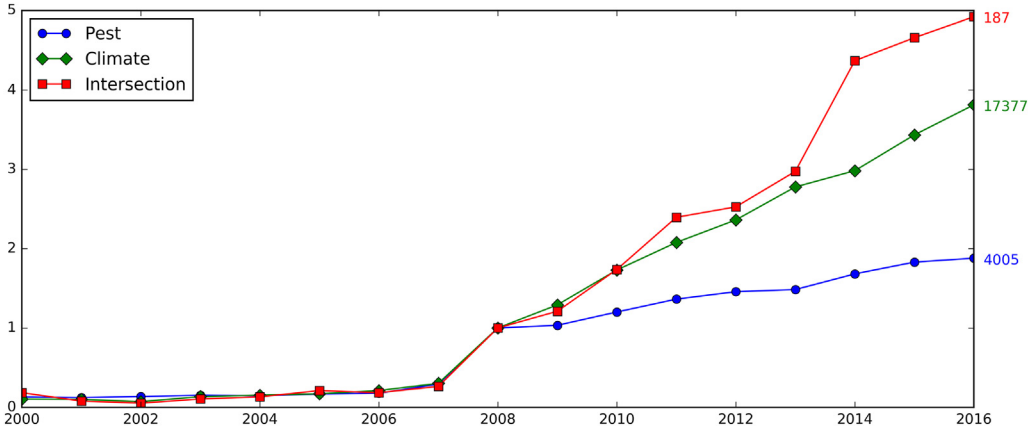

Fig. 1. Number of articles published in each category (pest – weeds, insects, plant pathogens, climate, and both data sets) for the period. Scale was standardized to 1 (y-axis) being equal to a level of that category in 2008. Numbers by each category are absolute numbers for 2016.

search of the Web of Science (WoS) database was conducted using two broadly defined search terms: "climate change" and "pest" with the assumption that the latter term is used by authors in paper abstracts and/or as a keyword that includes all disciplines (e.g., weeds, insects, plant pathogens). While other databases exist (e.g., SCOPUS), WoS provided the greatest number of papers. The search was restricted to articles published in English beginning in 2000, when the term climate change became prominent in the literature (Fig. 1). These terms selected 104,655 climate change and 30,559 pest articles for a total of 134,179 (last date of search: 17/05/01).

Articles from each search were downloaded and exported as tab separated text files. We extracted the first and last name of each author by searching for the regular expression /.*, [^ .]*/ within the name field using a data parser. We used the whole name field for entries that lacked the expression. Using this technique, we created subsets of articles authored by individuals with a specific last and first name.

For authors inconstantly using or not using their middle initial or papers having two different authors who shared the same name, we compared the affiliations of the authors. For our metric of how similar two affiliations were, we used cosine similarity of bigrams. This allowed us to subdivide the papers of authors who share a name into groups where each paper in a group had a similar cosine similarity to another (>0.4). If an author had multiple affiliations on an article, then all were used to find whether she or he had authored additional articles. The bigram basis of the method accommodates cases with many short shared substrings that may have different formatting (e.g., department, university, cities, zip codes). In the future, author global identifiers (e.g., ORCID) would be more robust, although not all authors have such identifiers.

Ultimately, we were able to define the domain of the authors to be either "climate change" or "pest" depending on affiliation and the data set in which we found the majority of their articles. Authors who had an equal number of articles in both categories, which we assumed were few, were not included in this part of the analysis, as they often published only a single paper in each category making the determination of where their expertise lies nearly impossible.

3. Results and discussion

The lack of peer-reviewed publications with pest management and climate scientists as co-authors may be an indicator as to the slow rate of progress in addressing the challenges increasingly associated with pests and climate change. While collaboration is needed between scientists working on general climate and biology relationships, equally important is the coproduction of knowledge by climate and pest management scientists working on pest organisms responding to climate change.

Our study brings to light the collaboration gap in the pest management and climate sciences. Of the 134,179 published papers on climate and pests, 0.8% (1035) were included in both climate change and pest datasets. The articles comprised 3.4% of the total number of pest-related articles and 1.0% of the total number of climate change-related articles, thus signaling the status of the exchange of knowledge and collaboration between the two fields. Since 2000, overlap in research that involves both fields increased at a relatively constant rate with a high of 187 articles at the intersection of pests or climate (Fig. 1). While the trends in articles are similar to the fields (pest, climate) and their intersection, a significant gap exists in the numbers.

The coproduction of knowledge occurs when ongoing relationships between scientists are built, two-way communication is ensured, and useable science is the focus (Meadow et al., 2015). Omitting one or more of these factors can prevent the field(s) from moving forward and not fully addressing the urgent environmental challenge of pests and climate change. Not surprisingly, we found that individual researchers are unlikely to publish articles in both climate change and pest disciplines (Fig. 2). Only 8.2% of the authors who have published

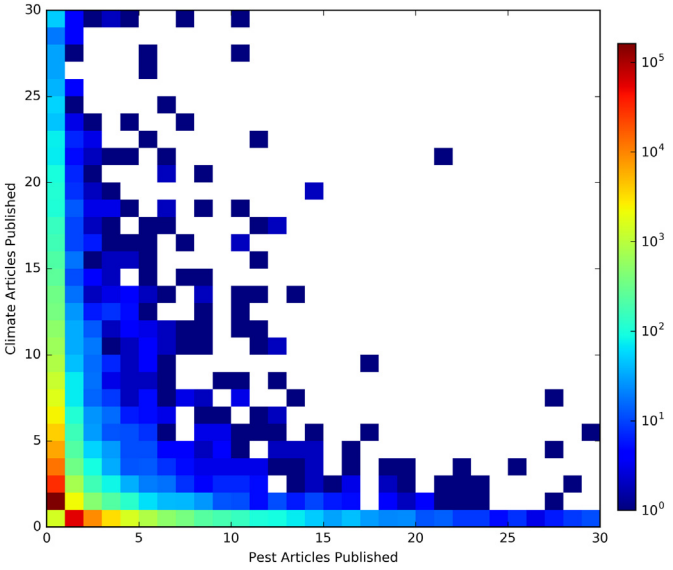

Fig. 2. A logarithmic heatmap of individual authors and the distribution of their articles between the two disciplines. Pests refer to weeds, insects, and plant pathogens.

papers in our pest dataset have also published in our climate dataset and 2.8% of those who have published in the climate change dataset have published in the pest dataset. Even those who do publish in both fields tend to do so rarely; of those authors who have published in both datasets, 83% published only a single article in at least one of the datasets. Publishing numerous papers is even rarer: only 136 of the 306,912 (0.044%) authors in our dataset have published five or more articles in both domains, which we contend has limited our ability to better address the increasing problems of managing and monitoring pests in a changing climate.

The author composition of individual articles also provides valuable insight (Table 1). For articles that are included in both datasets, 24% were written collaboratively between at least one researcher who specializes in each discipline (where specializes is determined from the relative number of papers published in each dataset, as discussed in the methods). Climate and pest management scientists wrote 39.1% and 25.1% of articles, respectively, where the topic spanned both disciplines. It is clear that articles which only appear in one of the domains are almost always written by authors from that domain (98% climate and 91% pests). Again, these results highlight the fact that collaborative research is largely lacking among pest management and climate scientists. Yet, questions remain as to whether greater coproduction of knowledge would equate to a better understanding of 1) pest response to climate change, 2) pest distribution and outbreak patterns, and 3) management and monitoring practices impacted. As an example of how these questions are being addressed, we used the Atopica project as a case study.

In 2011, a team of individuals developed Atopica (Atopic diseases in changing climate, land use and air quality – www.Atopica.eu), which was a project funded by the European Commission (EC; grant agreement no.: 282687) to address environmental change and the effects

Table 1
Articles categorized according to the discipline of the author (s) – climate or pest science. The rows represent the three categories: (1) only written by researchers specializing in climate change, (2) only written by researchers specializing in pest research, and (3) written collaboratively between at least one author who specializes in each field.

Authorship of article	Articles only in climate change	Articles only in pest	Articles in both datasets	All articles
Climate researchers	98.4%	0.6%	44.5%	76.6%
Pest researchers	0.1%	90.8%	28.5%	20.2%
Climate and pest researchers	1.5%	8.6%	27.0%	3.2%

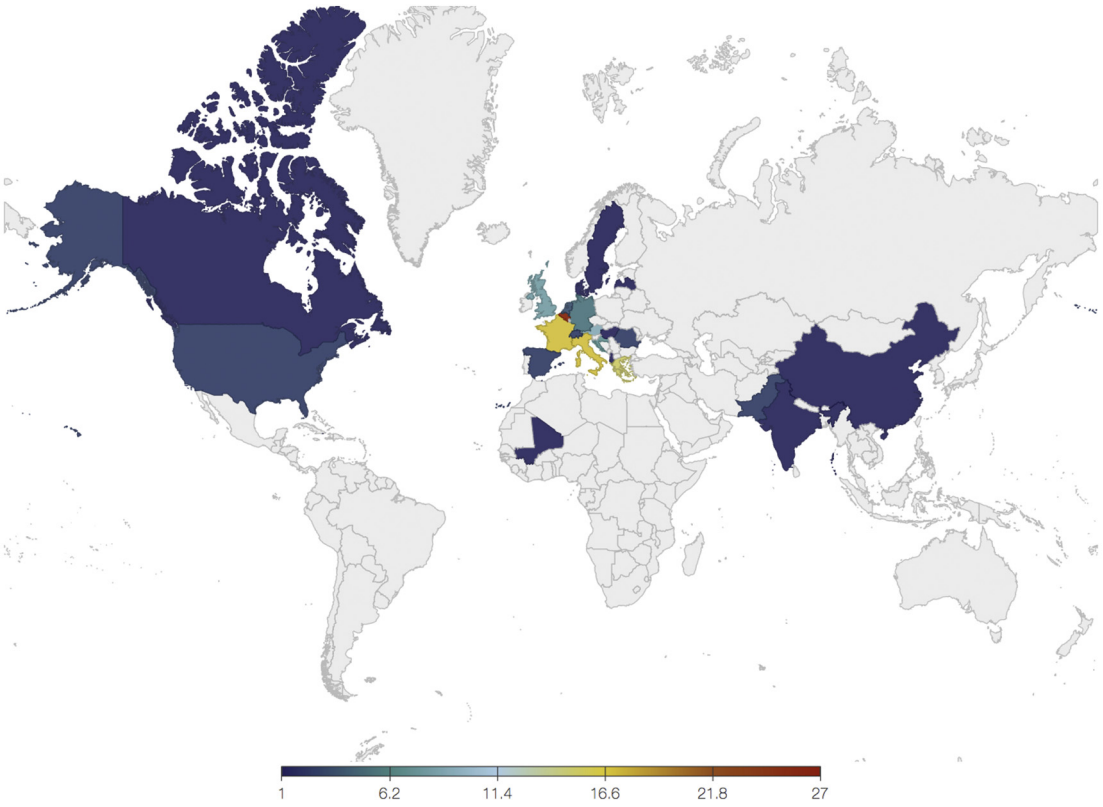

Fig. 3. Total number of Atopica project partners and meeting attendees from countries around the world at the Atopica Conference: Pollen is in the Air – Invasive Plants and Allergy in Our Changing Environment (https://www.atopica.eu/#).

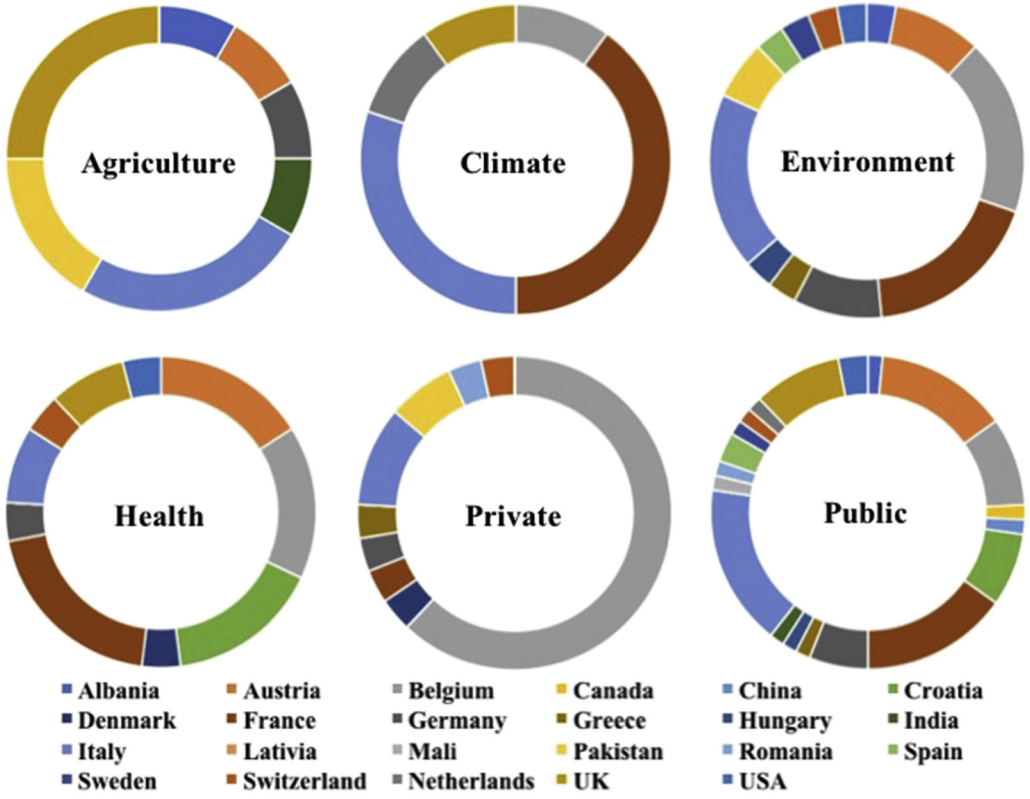

Fig. 4. Total number of individuals involved in the Atopica project and meeting attendees at the Atopica Conference: Pollen is in the Air – Invasive Plants and Allergy in Our Changing Environment (https://www.atopica.eu/#). Countries representing organizations (Public and Private) in the fields of human health (Health), agricultural research (Agriculture), climate science (Climate), and natural resources (Environment).

on atopic diseases (allergies, asthma, eczema) in Europe. The main requirements for the Atopica team were to 1) investigate how factors such as climate variability, the spread of invasive plant species, and land use changes affect the spatial and temporal distribution of airborne allergens, in particular, pollen; and 2) determine the effect of these changes on the prevalence of atopic diseases in Europe, especially among vulnerable groups such as children under the age of ten, the elderly, and people with chronic disease.

The Atopica team consisted of individuals with expertise in cellular and molecular biology, immunology, allergies, dermatology, physics, climate and air quality, and land use and they represented the countries of Austria, Italy, Croatia, France, Belgium, Germany and the United Kingdom. Individuals were from mainly academic, public institutions, which included universities, research institutes, hospitals, as well as small and medium-size enterprises, and an international organization. The objectives of the Atopica team were centered around airborne pollen concentration variability, effects on pollen allergenicity, sensitization and allergenic diseases in vulnerable groups, risk assessments, and health care and policy impacts.

The Atopica team used a comprehensive approach that was based on a unique blend of theoretical, and computer modelling work, field campaigns, clinical studies, and laboratory experiments to address the interaction between environment and pollen and how these changes influence pollen allergenicity. All data including epidemiological and environmental simulations of climate, air quality, and pollen were collected and used to develop a range of appropriate dynamical, statistical and laboratory models to quantify the disease response to environmental stressors.

During the project, a subset ("climate") of the Atopica team identified climate conditions conducive to pollen emission, spread, and outbursts. In papers published by the climate team (see Laguel et al., 2015 and Storkey et al., 2014), they provide gridded simulations of recent past and projections of future airborne birch, *Ambrosia artemisiifolia* L. *pollens*, O_3, NO_2 and particulate matter concentrations and uncertainties. Another Atopica subset ("clinical") team determined the prevalence and future incidence of allergy to *A. artemisiifolia* in children as well as the morbidity and severity coming from different levels of exposure during three consecutive pollination seasons. They also established the clinical relevance of *A. artemisiifolia* sensitization in elderly patients with new onset eczema in a region with new exposure to *A. artemisiifolia*. Together, the climate and clinical Atopica teams, quantified spatial and temporal dimensions of the association between pollen exposure and allergy (prevalence, severity) using regional case studies. (see Lake et al., 2016). A third Atopica subset ("allergy laboratory") team studied the influence of air pollution and climate-modified allergenic pollens on allergic asthma and the associated mechanisms, which they plan to publish (Epstein, personal communication). Taken together, the transdisciplinary aspect of each subset contributed with added value to further understanding of the impending health problems due to the climate change effect on ragweed invasion.

Atopica included diverse teams of researchers and a variety of stakeholders, such as non-governmental organizations, health authorities, and international groups, who represented the fields of health, climate, agriculture, environmental science, and journalism. In 2015, the Atopica team hosted a final conference for the project that included individuals from 25 countries (Fig. 3) representing 74 public and 29 private institutions (Fig. 4). In the fields of human health, agricultural research, climate science, and natural resources, individuals held positions in government (36), university (24), research institutes (20), consultant firms (17), patient organizations (13), and non-governmental organizations (7). Unlike the National Forum on Climate and Pests, numerous collaborations were developed through Atopica and several follow up grants have been written to continue research specifically focused on climate change and the impacts on an important pest species.

4. Conclusion

A large amount of peer-reviewed research is published on climate change and pest management science, yet the low numbers of co-authors representing each discipline are evidence for lack of cross-disciplinary activity. Is this gap intentional or simply an unrecognized opportunity by individuals working in two different fields? The silo effect, which is the separation of individuals in a field of study or across several fields, is common in academia. Our results support this general phenomenon. However, a group like Atopica, which has brought together a diversity of individuals around a common topic, is an example of knowledge being coproduced to better understand and more quickly address a problem. By involving researchers in the health, climate, agriculture, and environmental science fields, the basic research that has emerged from the group (e.g., Storkey et al., 2014; Laguel et al., 2015) is the basis for applied studies (e.g., Lake et al., 2016) that will support better land management practices that are adapted to climate change to reduce a major pest plant. Atopica is an example of a deliberate and incentivized approach that did not have as its goal to improve collaboration among faculty, but instead to address a major societal challenge. In the end, the silos disappeared along with what is hoped will be *A. artemisiifolia*.

Acknowledgements

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